Infiltrometers for restoration site evaluation

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One of the key factors in understanding disturbance and developing restoration plans is the flow of water on, across and into a site. The reduced ability of water to move into the deeper soil if often a critical concern. Infiltration is usually measured indirectly as the difference between the water applied to a given area compared to the water that doesn't enter the soil and runs off, often as cm/hr or cm/minute. It can also be related to the rate of movement of water into the soil from a bounded, but open bottomed reservoir. To minimize the effects of lateral flow out under the edges of the reservoir area a second ring reservoir is often added. For more on the theory of infiltrometers see Johnson (1991).

Infiltration is a complex process related to soil composition and texture (particularly organic matter), soil microtopography, macro and micropore sizes and numbers (often created by soil organisms), soil compaction, soil moisture, soil cryptograms (fungi and other living soil crusts) and the benefits of stem flow and other effects from vegetation (Bainbridge, 2007; Beven, 2004). The stability of the soil particles and aggregates is also important. If rainfall impact breaks down aggregates it can create a sealed surface that limits infiltration. In undisturbed ecosystems the variation in infiltration across space is often very high. Disturbance usually adversely affects infiltration in many ways, from increased compaction destroying soil pores, to declines in vegetation, loss of microtopography, reduced aggregate stability, destruction of soil organisms and many other factors. A study of infiltration by disturbance at Anza Borrego Desert State Park illustrates the changes that may occur, figure 1.

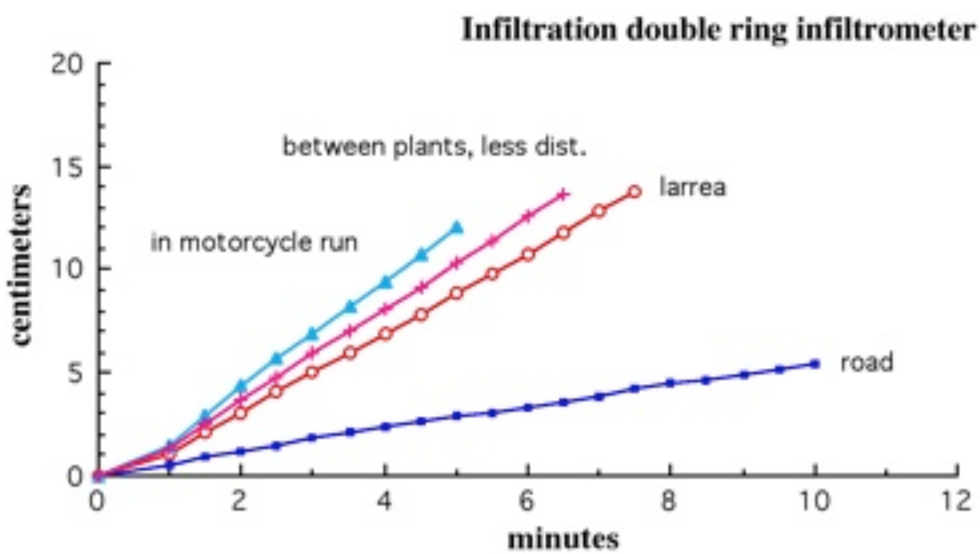

Figure 1. Infiltration by disturbance type Anza Borrego Desert State Park.
The motorcycles remove the dust and clay leaving a coarser sand.

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Infiltration is usually measured with an infiltrometer or a sprinkling infiltrometer. The typical double ring infiltrometer requires considerable time to set up and run, figure 2. It also uses large quantities of water, up to several hundred liters per hour. These factors make it unsuitable for remote sites and studies of less disturbed ecosystem soils that often have very high heterogeneity and where many tests should ideally be run. These large double ringers are better suited for agricultural fields where large areas have been made relatively uniform by repeated tillage.

Sprinkling tests are preferred but can be complex and generally require substantial amounts of water. This often rules them out for remote sites. In 1951 the USFS started using an infiltrometer developed by Dortignac (1951) but it had very high water requirements. The USGS developed a micro-sprinkling infiltrometer more suitable for remote areas based on an earlier Ph.D. dissertation by J. E. Adams at Iowa State (McQueen, 1963). This needs only 4-8 l/h, figure 3. This research explored different methods of preparing the capillary holes to change rain drop properties. With careful drilling for the rain drop-making holes they achieved uniform application rates as low as 2 cm/hr with a minimum hydraulic head of 2.5 cm.

Figure 2. Large double ring infiltrometer tests

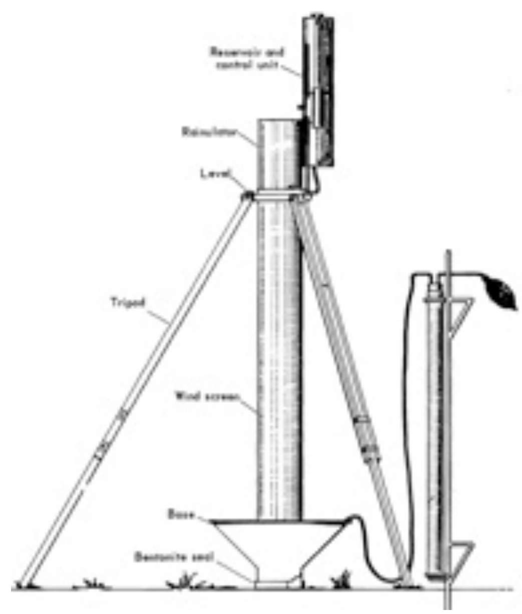

Figure 3. USGS Portable sprinkling infiltrometer

The Cornell micro-sprinkler infiltrometer is further refined with a single 24.1 cm (9 1/2") inner diameter infiltration ring and a constant head reservoir (Ogden et al., 1997; van Es and Schindelbeck, 2012), figure 4. Capillary tubing is used to make rain drops. The soil has to be good enough to drive or set the ring into the soil 7 or 15 cm. At times they have used a tractor with a hydraulic ram to push the rings into dry soil. A small backhoe with a bucket also works but they recommend attempting infiltration tests when the soil is damp due to issues with achieving field-saturated conditions without the help of rainfall. In

Figure 4. Cornell micro-sprinkler infiltrometer

addition if the soil is moist it is easier to set the ring. This design has been well tested and permits the determination of several important soil hydrological properties including: time-to-runoff, sorptivity, and field-saturated infiltrability. A thorough field manual is available free on line (van Es and Schindelbeck, 2012).

Alternative infiltrometers for remote sites

Beginning in 1986 I have designed, built and tested a variety of infiltrometers in an effort to develop a low cost infiltrometer that would use very little water, be easily carried over hill and dale, survive bashing around in the back of a truck, and be easily set up and monitored by one person. The most effective design was a reduced size double ring infiltrometer using a graduated cylinder for the water reservoir, plastic pipe for the inner ring, running at relatively constant head with an air vent into the ring reservoir, and using a steel cooking pot with the bottom cut out and the edge sharpened for the outer ring, figure 5. I had previously tried a very heavy section of steel pipe with a sharpened edge and a galvanized bucket with the bottom cut off for the outer ring but both were awkward to haul around and insert in the soil. The kitchen pot ring was easy to carry and the handles made it easier to saw it into the ground, figure 6. Many tests could be run with the water in one 20 l (five gallon) jug. The infiltrometer was inverted, filled with water and then flipped quickly and set into the already filled outer ring. This gave very consistent results, figure 7. It was still cumbersome and relatively slow, limiting the number of tests that could be run in a day.

Inspiration struck one day while I was shifting material in our storage area and found a box of off-cuts of clear mini-rhizotron pipe (mm diameter x mm tall x mm thickness) used in video studies of root development. I made multiple copies of a cm ruler on a paper sheet and then made an overhead transparency. These rulers were then cut out and fastened to the short plastic tubes with heavy duty 3M packaging tape. For simple

Figure 5. Bainbridge microinfiltrometer

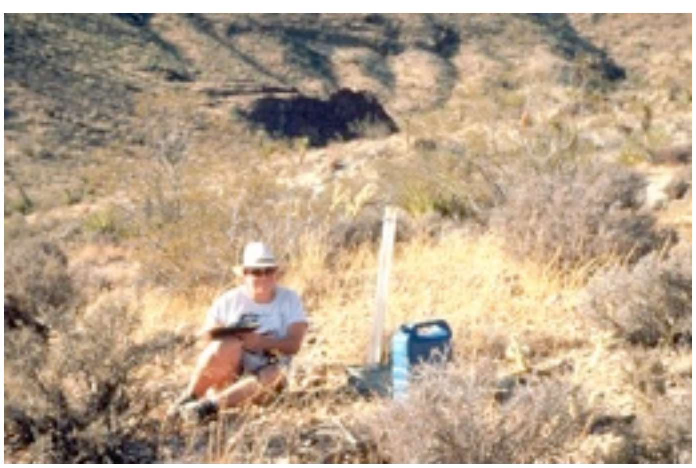

Figure 6. Bainbridge micro-infiltrometer

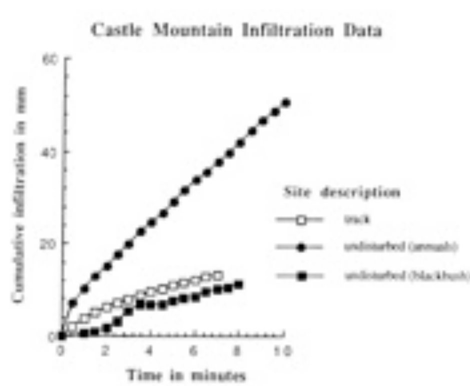

Figure 7. Micro-infiltrometer results Mojave desert

infiltration studies a series of these metered plastic tubes are set into the soil. The tubes are filled with water from a bottle with a j-tip so the water does not jet into and disturb the soil. Infiltration is measured by noting the fall of water in the tube over time. In some cases a little mud has to be made to seal the tube edges before filling. Using a timer the readings are taken periodically with the interval in seconds or minutes depending on the soil type.

Figure 8. Tube infiltrometers and hole saw

Observing my struggle to set the tubes in severely compacted soil one of my students (Ian Delgado) suggested using a hole saw, figure 8. Great idea. A hole saw (with the pilot bit removed) matching the pipe diameter is inserted in a hand brace or rechargeable drill and used to cut a ring slot for the pipe. The dust is wetted to make a good seal. These pipe infiltrometers proved to be very effective at measuring many locations at the same time, revealing the wide variations possible in a small area. Although this is not a constant head device it still provides a quick and useful comparison between sites. The measurements are repeatable and instructive, figure 9.

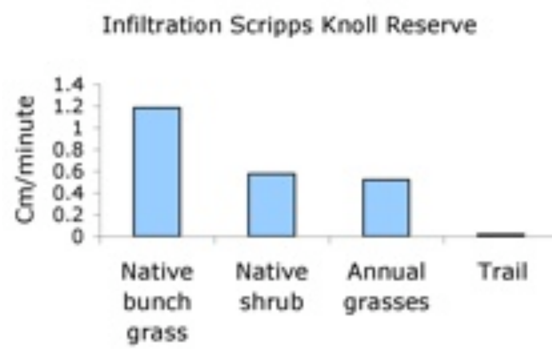

Figure 9. Scripps Knoll Reserve, Restoration class results

As an even cheaper option we tried metal cans with the bottom and top cut off. These are simply twisted into the ground, filled with water and then the drop in height is measured and converted to cm/min. Very crude but useful comparisons can be made.

Site recovery and monitoring

Recovery from compaction is very slow in areas without winter freezes, because no frost heaving occurs. Infiltration rates in Mojave desert tank tracks were less than half that of undisturbed areas nearby even after five decades of recovery (Prose and Wilshire, 2000). The removal of vegetation by disturbance can further reduce infiltration as plant-mediated infiltration benefits (stem flow, litter, etc.) are eliminated. Infiltration in dry creosote bush soil was double that of dry bare soil, and infiltration in wet creosote bush soil was almost five times higher than in wet bare soil (Tromble, 1980). I found infiltration in Selaginalla covered soils was much faster than adjacent bare soils. During intense rains these changes in infiltration are accentuated. Areas with good plant cover may hold and save much of the rain that falls in intense storms while areas that have been disturbed experience sheet flow, flash floods, and severe erosion. Infiltration studies and particularly sprinkling type infiltrometers are good for these comparisons. In addition it can be helpful to do an analysis of surface micro-topography to estimate surface water storage capacity. The more water that is held the greater the infiltration as the rate doesn't matter as much. Storage capacity can be estimated with a low cost microtopography recorder, figure 10, or a laser measuring device. Training on infiltrometers and microtopography gauges should be included in restoration site assessment courses, figure 11.

Figure 10. Microtopography recorder

Figure 11. Infiltrometer training Society of Ecological Restoration desert restoration course at Red Rock Canyon State Park

Summary

Infiltration is a key factor in understanding site disturbance and planning restoration work. Deep ripping for example has doubled water at 5 feet (5 volume) in the Pacific Northwest. The perfect infiltrometer for remote sites has yet to be invented but the Cornell system looks very good for soils with decent tilth where the ring can be set. The supporting materials are excellent as well. The USGS model also has potential with its lower water use. For much lower cost infiltrometers try making a set of very low cost single ring infiltration tubes. It can also be fun and instructive to try building your own double ring or sprinkling type infiltrometers. This could also be a good class assignment. The infiltration data gathered can be very helpful in determining site restoration protocols or management strategies. They can also be used as an important factor in monitoring site recovery or decline over time.

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van Es, H. M. and R. Schindelbeck. 2014. Field Procedures and Data Analysis for the Cornell Sprinkle Infiltrometer. Department of Crop and Soil Sciences Research Series R03-01. For further information on operation and purchase contact Robert Schindelbeck rrs3@cornell.edu.

http://soilhealth.cals.cornell.edu/research/infiltrometer/infil_manual.pdf

https://www.youtube.com/watch?v=sMUGmX_3EQM

Approximate cost: 24"OD x 12" ID double ring $2300; Cornell micro-sprinkle infiltrometer and accessories $1200-1500; tube type infiltrometers (acrylic, polycarbonate, or CAB (Cellulose Acetate Butyrate) $2-10@; home made double ring using graduated cylinder, plastic pipe fittings, and cut off steel pot ~$50.